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The Met. Office Doppler Radar Project: Progress and Plans

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The Met. Office Doppler Radar Project: Progress and Plans

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Summary

This report is based on an (FR) division seminar given on Thursday 9th September 1993. Some applications of Doppler radar data to forecasting in different countries, and the basic interpretation of Doppler displays, are discussed in Lilley (1990). This report summarizes the progress made and plans for work with Doppler radar within the UK Met. Office.

Two of the UK's network of operational radars, at Cobbacombe Cross and Clee Hill, have Doppler capabilities. The information collected is the component of the air motion parallel to the radar beam, and data are only available in precipitation. (FR) division are interested in using these data as input to the Mesoscale Model, and as a first step towards this, their accuracy and reliability is being evaluated. A substantial part of the talk consisted of examples of the various displays available from the radar at Cobbacombe Cross, including comparison with winds observed by radiosondes. Other groups are also interested in using Doppler radar data for various purposes, and Fig. 18 shows some projected timetables.

1. Basic principles

Doppler radar works by measuring the Doppler shift in the frequency of the radiation received back at the radar, relative to that transmitted (Fig. 1). (The effect is the same as the change in pitch of the sound heard when a fast-moving vehicle passes a stationary observer.) This means that the radar must emit radiation with a coherent frequency, which is technically more difficult to produce than is the non-coherent radiation used for intensity-only radars. For meteorological Doppler radar, the radiation is reflected off raindrops or other hydrometeors, which act as tracers of air motion; thus the information is only available when it is raining.

The information returned is the component of the velocity of the reflector parallel to the radar beam. As the beam sweeps round 360°, it observes a maximum of wind towards the radar, reducing to zero as it scans perpendicular to the wind direction, increasing to a maximum away from the radar, and returning to zero again. From this pattern, we can derive the average wind over the area, or we can use the detail in the data to derive information about how the wind varies horizontally and vertically. In order to recover the full three-dimensional wind, either we need three radars in different places scanning the same area, or we must make assumptions, such as the fall-speed of raindrops and the way in which the wind usually varies, or we can use the data as input to a numerical model which in effect imposes its own set of assumptions.

2. The project and its philosophy

The UK currently has 12 operational radars, plus one in Jersey and two in the Republic of Ireland (Fig. 2). Currently, two of these have Doppler capabilities; these are at Cobbacombe Cross, in North Devon, and Clee Hill, in Shropshire. The three in Scotland could be reasonably easily upgraded, and part of the aim of the Doppler project is to decide whether or not is is worth upgrading these radars and replacing the other radars in the network with Doppler radars in due course.

(FR) division's main interest in Doppler radar is to use it as input to the mesoscale model, so we are looking at the output from the Cobbacombe Cross radar to see how accurate and reliable it is and how useful it would be in the model. Another major use of Doppler data is in removing clutter and anomalous propagation (anaprop); in general these do not move, so they

have zero Doppler velocities. Quite how effective this is in removing clutter and anaprop without removing the signal from rain is something that (OI) intend to look into.

Another aspect of the radars at Cobbacombe Cross and Clee Hill is that they are fully steerable and scan rather quicker than the other radars in the network. Thus we can carry out volume scans and get three-dimensional reflectivity and Doppler velocity data. How much use these data will be in the model or elsewhere requires assessment.

3. History of the project

At this point I would like to acknowledge the other groups who have helped make the project happen, in particular Bill Wheeler's group in (OI), who got the radar in place and working, and the Telecomms centre, who got it to communicate with the workstation in room 341.

Fig. 3 is a summary of the history of the Doppler project. The idea for the project was first floated in 1987 (as far as I can find out). A cost-sharing contract was agreed with Plessey Radar (now Siemens Plessey Systems) in early 1989 to develop and supply a prototype system consisting of a modification to one of the existing radars and a workstation for analysis of the data. The original intention was to Dopplerize the Wardon Hill radar, in Dorset.

Plessey subcontracted to a company called Lassen in the USA to develop most of the software for the workstation. During the development phase, there were numerous delays in writing the software and getting the workstation working properly. There were also some problems with developing the hardware; one result was that it was considered better to Dopplerize the Cobbacombe Cross radar (which is a fill-in site) than Wardon Hill (which is more critical to the network).

The workstation was paid for in the financial year 1991–2, and we took delivery in June 1992. It was installed, set to work and commissioned in January 1993, and after further problems with the radar hardware, Plessey gave us a demonstration of the system at Bracknell in April.

4. Characteristics of the radar

Fig. 4 is a summary of the characteristics of the Cobbacombe Cross radar. It is a C band radar, i.e. about 5 cm wavelength, like all the others in the UK network. Most Doppler radars, notably the NEXRAD network in the USA (see e.g. Klazura and Imy, 1993), are S band (10 cm), which suffers less from attenuation in heavy rain but is less sensitive to light drizzle and is more expensive as a bigger dish is needed for the same beam-width. Also our system is much lower powered than NEXRAD—only 250 kW peak power compared to 1000 kW. These differences mean that we can expect to see much less signal in clear air than the NEXRAD systems, which routinely detect enough "angels" (mainly refractive index anomalies) to give useful data even when it is not raining. At C band, what clear air returns we do get would be most likely to be from insects and birds.

The Cobbacombe Cross radar is part of the UK radar network, and in order for it to operate as similarly as possible to the other radars, it spends $2^1/_2$ minutes out of every 5 scanning in intensity mode only, collecting data from the 4 standard elevation angles for the network. The remaining $2^1/_2$ minutes is available to the user of the workstation at Bracknell to request Doppler or volume scans, and products are sent back up the line to the workstation. In practice the amount of data that can be looked at is limited by the speed of the line rather than the time available for Doppler scanning.

5. Examples of the workstation's displays

Figs 5–8 show several different displays of data collected at 07:21 GMT on 12th May 1993. Fig. 5 is a plan position indicator (PPI) of intensity, which is virtually identical to the output that can be obtained from any of the radars in the network. It shows a band of light showers moving up from the south, together with the clutter pattern, which is in dark red and orange and can be readily identified as it does not change from day to day. There are range rings every 25 km. Fig. 6 is the corresponding PPI of Doppler velocities, showing winds blowing along the band from east to west (the rule for the colours used is Red Away, Blue Towards the radar), plus a lot of noise (speckled effect) in the areas where there is no rain and hence there is no useful signal in the Doppler returns.

Fig. 7 is a PPI of Doppler velocity for the same time but at a higher elevation angle than Fig. 6. This is similar to Fig. 6 but shows a smaller area because the beam is overshooting the more distant precipitation. It shows the wind veering a little with height; this can be deduced from the S shape of the zero contour (between the red and blue areas) to the southwest of the radar.

Fig. 8 is a wind profile derived from a velocity-azimuth display (VAD). Winds are sensed by the radar around a circle at a certain height, and a sinusoidal curve is fitted to these winds; the curve represents the Doppler velocities that would be sensed by the radar if a uniform wind were blowing across the entire area scanned by the radar at that height, and the whole area were filled with rain. The speed and direction of this uniform wind are plotted on the VAD graphs, and the process is repeated for the next height. This particular display is derived from a radar scan at 4° above the horizontal. There are useful data up to around 5 km height, corresponding to a circle with radius 68 km from radar; above this height, there are too few precipitation particles for meaningful radar returns to be sensed.

Fig. 9 is a chart of 850 mb heights and winds, and surface fronts, on 17th May 1993. Fig. 10 is a low-elevation PPI of intensity for two hours earlier, showing rain associated with the frontal system moving into the radar area from the southwest. Fig. 11 is a PPI of velocity at a higher elevation; in this case, the winds are stronger than the unambiguous velocity of 39 kt, and where the Doppler velocity sensed is greater than this, "away" winds are plotted in the colours for "towards" motion of <39 kt (i.e. they are *folded*). The threshold of 39 kt could have been increased to around 95 kt, but only by reducing the range observed to 125 km. A schematic of the interpretation of the figure is superimposed on to Fig. 11; the arrows show the radial component of the wind. Note that there are peaks of wind speed both towards and away from the radar, with weaker winds further away; this indicates a low-level jet. Note that the wind speeds observed are consistent with those shown on the 850 mb chart (Fig. 9).

The PPI of intensity corresponding to Fig. 11 is shown in Fig. 12. On this figure, a bright band can be seen to the west of the radar site, around 25 km away from the radar. Fig. 13 is a range–height indicator (RHI), made by pointing the radar antenna along the line AB (Fig. 12) and nodding it. This shows the bright band well at just above 2 km height. This picture is shown back to front so that left corresponds to 200°, i.e. south-southwest from the radar.

Fig. 14 is a cross-section of intensity along the line AC (Fig. 12). This picture was created by interpolation from a "volume scan" consisting of 6 elevation angles, so it is much coarser and shows much less detail than does the RHI. Its advantage is that one can get a cross-section along any line, not just one passing through the radar site.

For completeness, the RHI (Fig. 15) and cross-section (Fig. 16) of velocity corresponding to the intensity pictures in Figs 13 and 14 are shown. These vertical sections tend to be rather difficult to interpret, and in many cases give little extra information.

6. Comparison with other data

Our main interest in Doppler data is to use them in the mesoscale model. With all the delays to the project, we have not got far beyond the planning stage on this. The first stage of using the data is to compare them with other data sources and try to ascertain how accurate they are. We are liaising with John Nash's group in (OP) to compare the error characteristics of Doppler data with those of data from the Aberystwyth wind profiler, and to compare the data directly with nearby radiosonde ascents. For example, comparing the VAD for 12th May (Fig. 8) with a Larkhill ascent (Fig. 17), we find a very similar shape to both the speed and direction profiles, although the speeds observed by the radiosonde are considerably higher than those derived from the radar observations. This is partly due to differences in time (over an hour) and place (over 100 km), and partly because the width of the radar beam and the VAD technique smooth out a lot of detail in the wind structure; there may also be errors in the calculation of the VAD. Comparisons are also planned with the radar operated by NERC at Chilbolton, in Hampshire, which scans an area that overlaps with that scanned by Cobbacombe Cross.

Once we have an idea of the accuracy of the observations, we shall be trying (in conjunction with the Mesoscale Modelling group) to assimilate them into the mesoscale model. Initially we intend to assimilate the VAD wind profiles, as they can be made to look like a radiosonde ascent and hence are easy to put into the model without writing any new code, but eventually we want to assimilate the single-component winds so that we do not lose too much of the detail in the wind structure. Obviously these data are only available to the model when it is raining, but that is exactly the time when data are most likely to be useful and when some other sources of data, e.g. satellite soundings, are least useful. I suspect that Doppler data will prove most useful to the model in slow-moving frontal situations (see Browning, 1989).

7. Use of Doppler radar in other divisions

Fig. 18 shows a summary of some of the work involving Doppler radar that it is projected to carry out within the Met. Office. Within (FR) division, the Nowcasting Development and FRONTIERS Development groups have expressed interest in the potential of Doppler for detecting anaprop and bright band, thereby producing cleaner rainfall analyses, and also in using Doppler data in an expert system to forecast convective development. There is also interest in using Doppler data in a system for forecasting local winds and convective turbulence for aviation; trials are planned involving the DRA at Bedford.

Another branch interested in using Doppler is (OI), who hope to carry out some studies into using Doppler to detect anaprop with a view to having automatic anaprop identification on site eventually. Defence Services are interested in using the displays in real time in some forecasting offices; a user trial of the data in CFO has begun, and trials may be held in a few outstations later.

Appendix

The following is an expanded version of the summary of the project's history shown in Fig. 3.

First outline of requirements	May 1987
Contract agreed to upgrade Wardon Hill	Feb 1989
Order placed for (FR)'s workstation	Oct 1990
Workstation delivered at Siemens Plessey (Cowes) and paid for	Mar 1992
Workstation delivered to Met. Office (Bracknell)	June 1992
Communications link installed	July 1992
Order placed to commission workstation	Oct 1992
Commissioning at Cobbacombe Cross	Jan 1993
Communications link functioning	Mar 1993
Radar acceptance testing at Cobbacombe Cross	Mar 1993
Demonstration by Siemens Plessey at Bracknell	Apr 1993

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Browning, K. A. (1989) The mesoscale data base and its use in mesoscale forecasting. *Q. J. R. Meteorol. Soc.*, **115,** 717–62.

Klazura, G. E., and D. A. Imy (1993) A description of the initial set of analysis products available from the NEXRAD WSR-88D system. *Bull. Amer. Meteorol. Soc.*, **74,** 1293–311.

Lilley, R. (1990) Applications and interpretation of Doppler radar data. Meteorological Office, Short range forecasting research, internal report **14**.

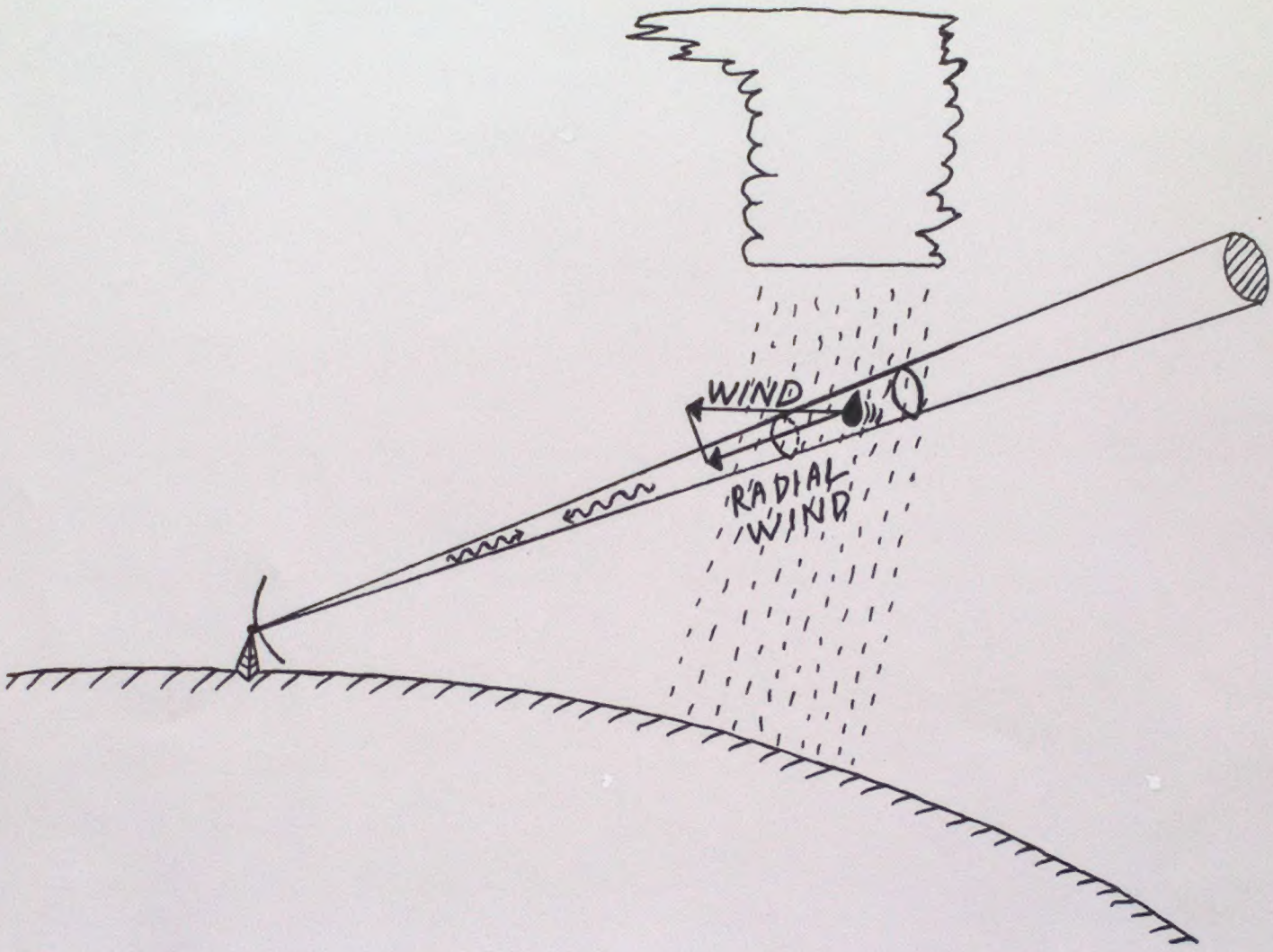

Fig. 1. The geometry of a radar pulse volume.

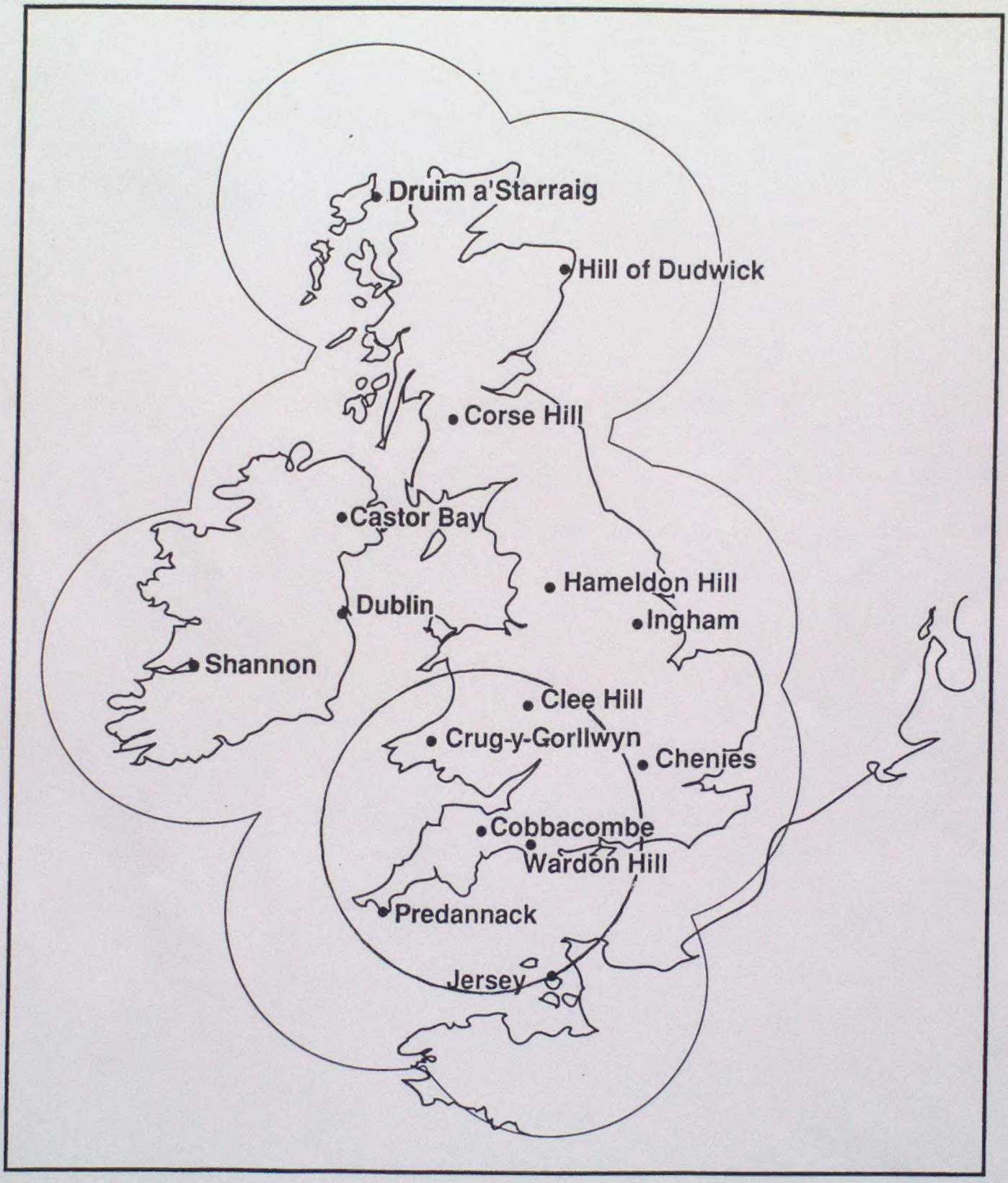

Fig. 2. Map of radar sites in the UK, Republic of Ireland and Jersey.

History of Doppler Project

First outline of requirements	May 1987
Contract agreed to upgrade Wardon Hill	Feb 1989
Order placed for (FR)'s workstation	Oct 1990
Workstation delivered	June 1992
Commissioning at Cobbacombe Cross	Jan 1993
Communications link functioning	Mar 1993

Fig. 3. Summary of the history of the Met. Office's Doppler radar project.

Radar Characteristics

Wavelength:	C band (5·3 cm)
Beam-width:	1°
Peak power:	250 kW
Detection:	*Intensity mode:* 1 mm/hr of rain in the lowest 3 km detectable up to 200 km *Doppler mode:* Unambiguous velocity ±95 knots to a range of 125 km
Displays:	PPI, RHI, CAPPI, Cross section, Accumulation, Echo tops, Echo bases, Vertically integrated reflectivity, Column maxima, Velocity–azimuth display, Storm centroid tracking

Fig. 4. Summary of the characteristics of the Cobbacombe Cross radar.

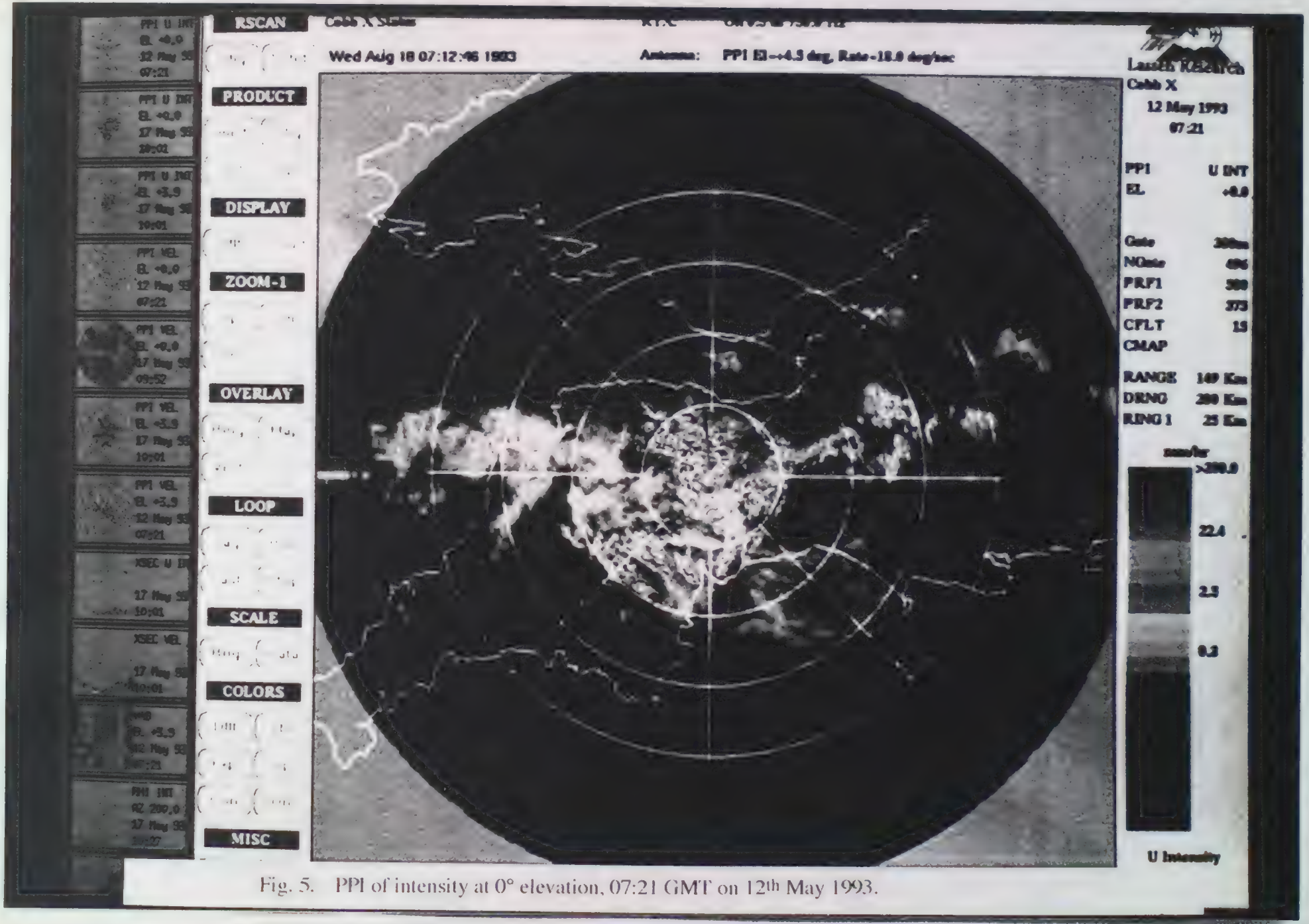

Fig. 5. PPI of intensity at 0° elevation, 07:21 GMT on 12th May 1993.

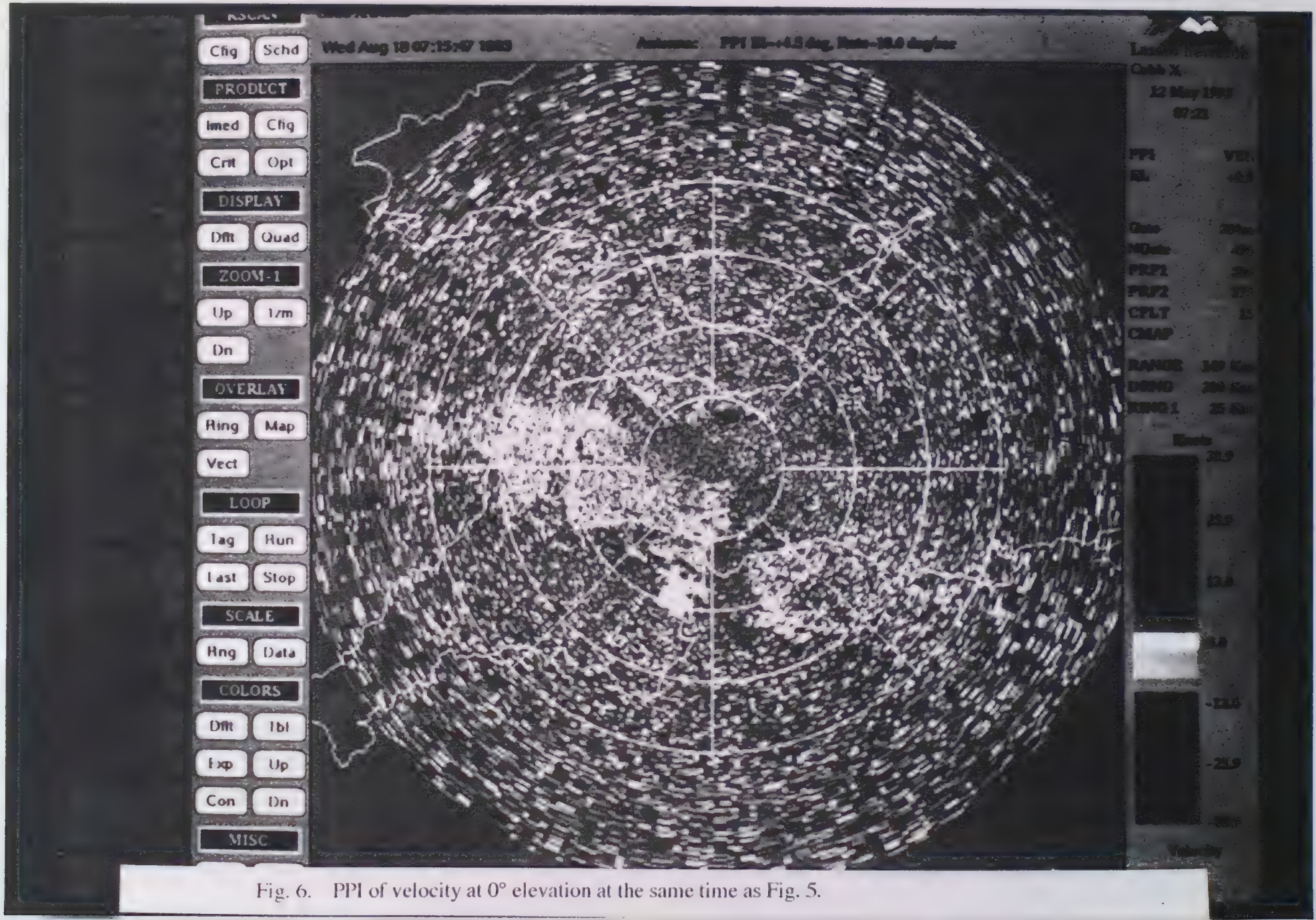

Fig. 6. PPI of velocity at 0° elevation at the same time as Fig. 5.

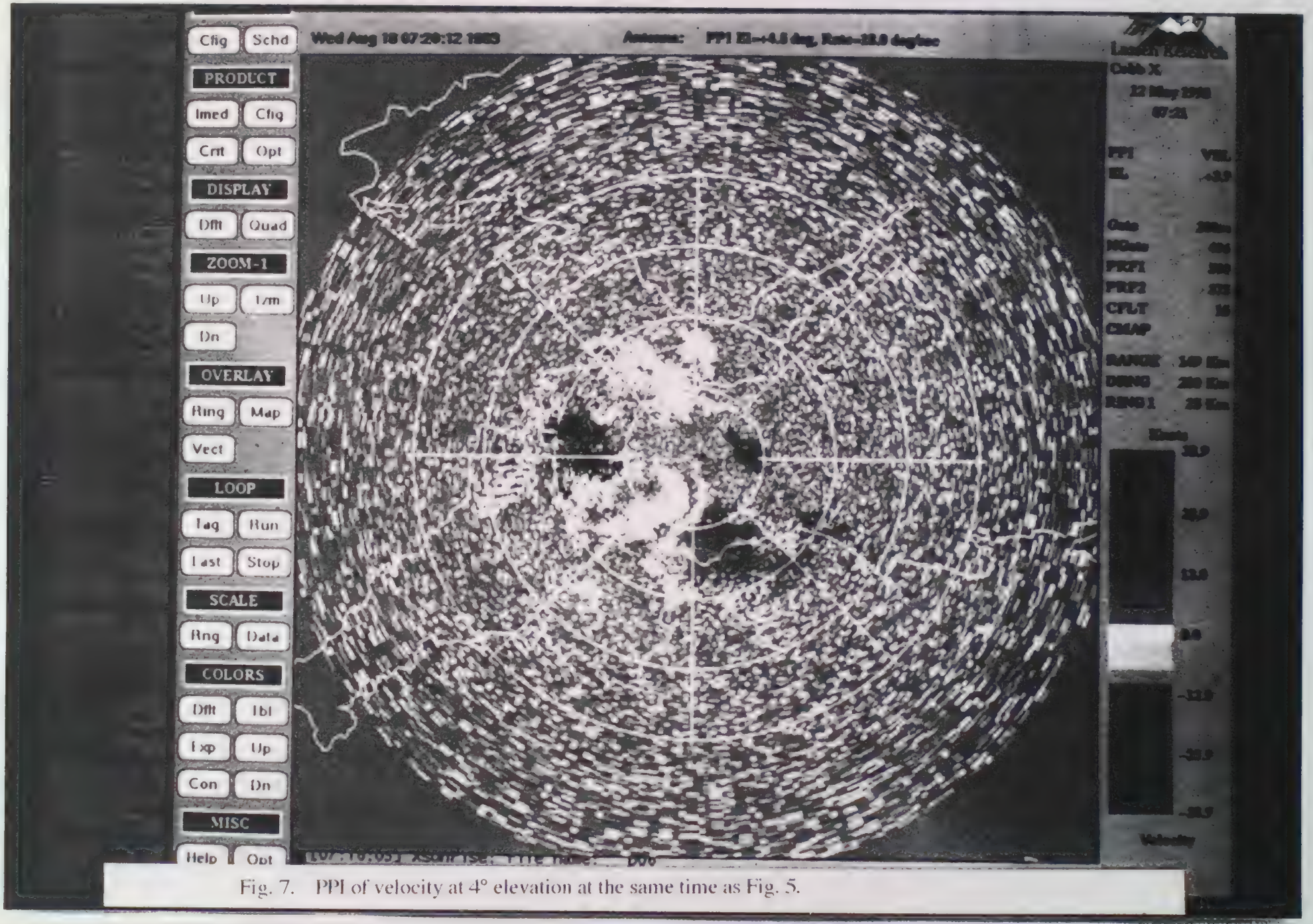

Fig. 7. PPI of velocity at 4° elevation at the same time as Fig. 5.

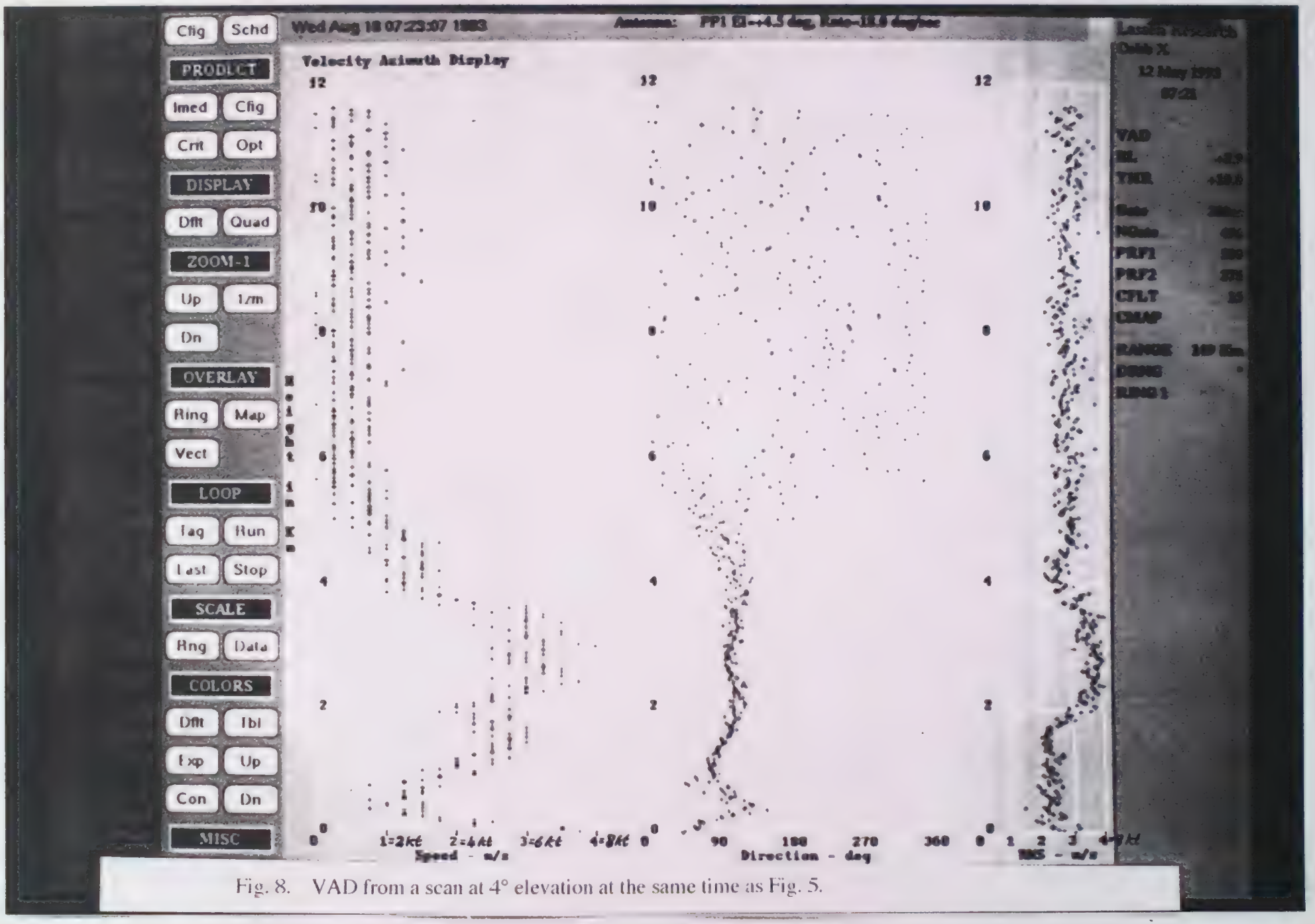

Fig. 8. VAD from a scan at 4° elevation at the same time as Fig. 5.

Fig. 9. Chart of 850 mb heights (in gdm) and winds, and surface fronts, at 12:00 GMT on 17th May 1993.

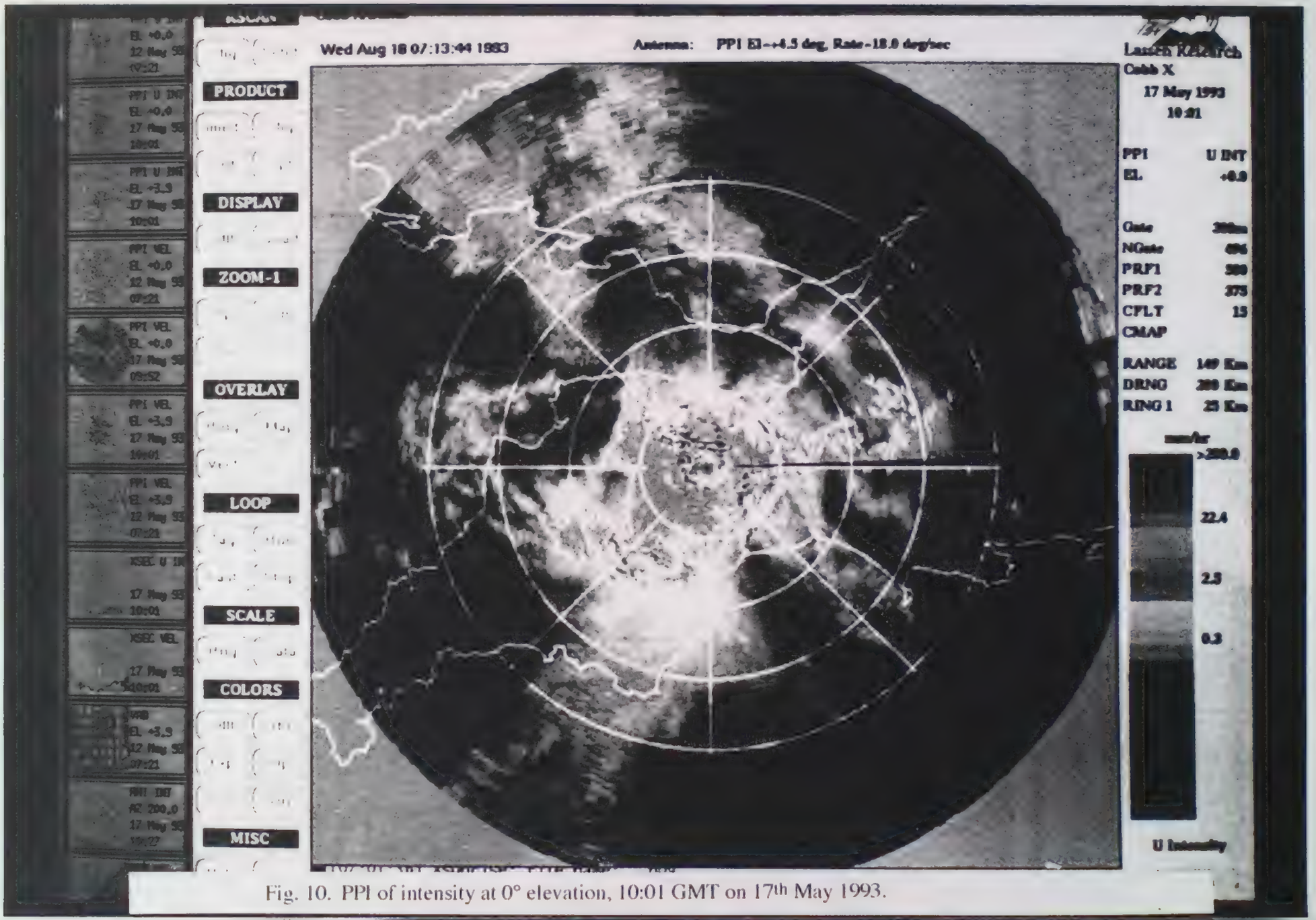

Fig. 10. PPI of intensity at 0° elevation, 10:01 GMT on 17th May 1993.

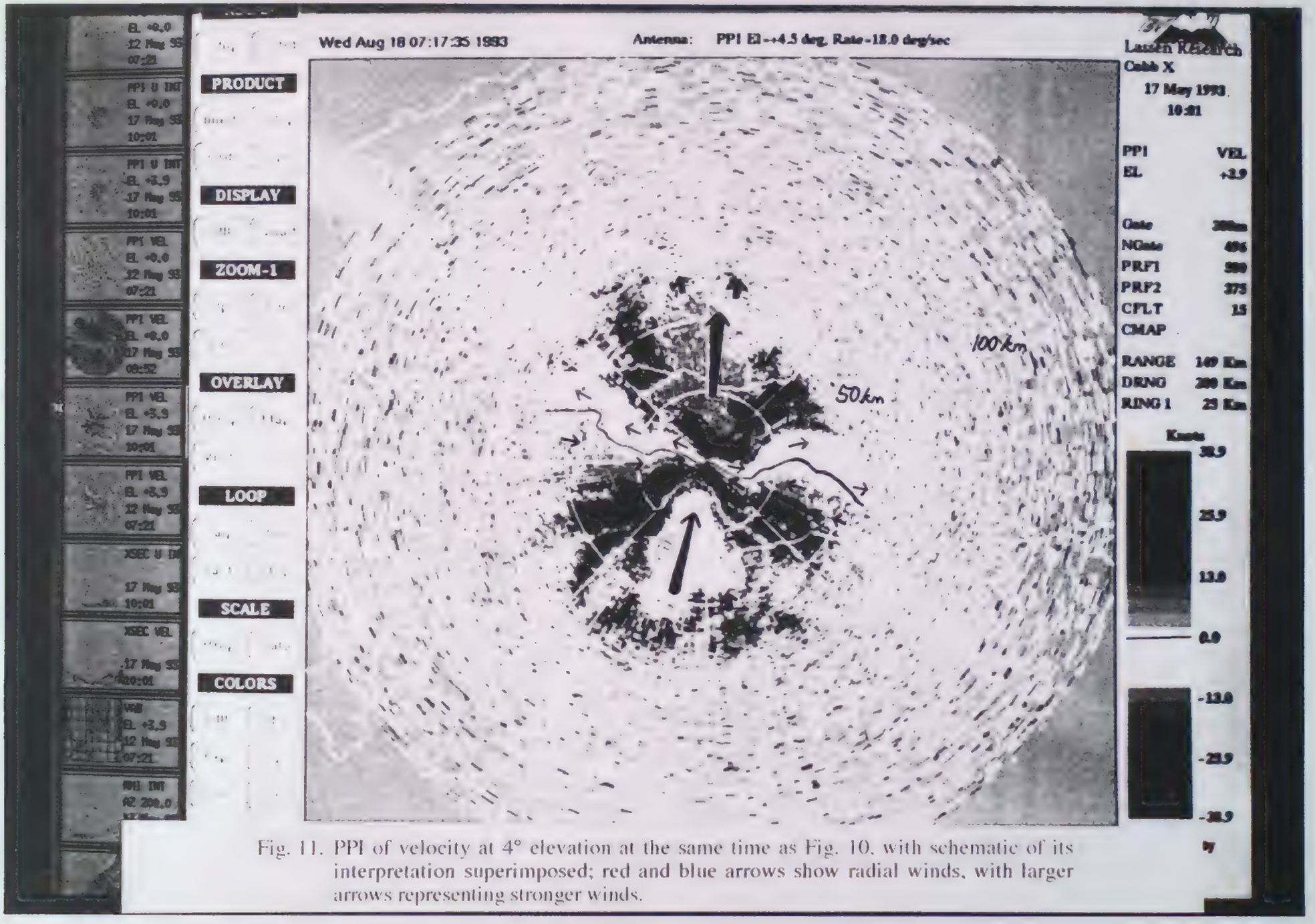

Fig. 11. PPI of velocity at 4° elevation at the same time as Fig. 10, with schematic of its interpretation superimposed; red and blue arrows show radial winds, with larger arrows representing stronger winds.

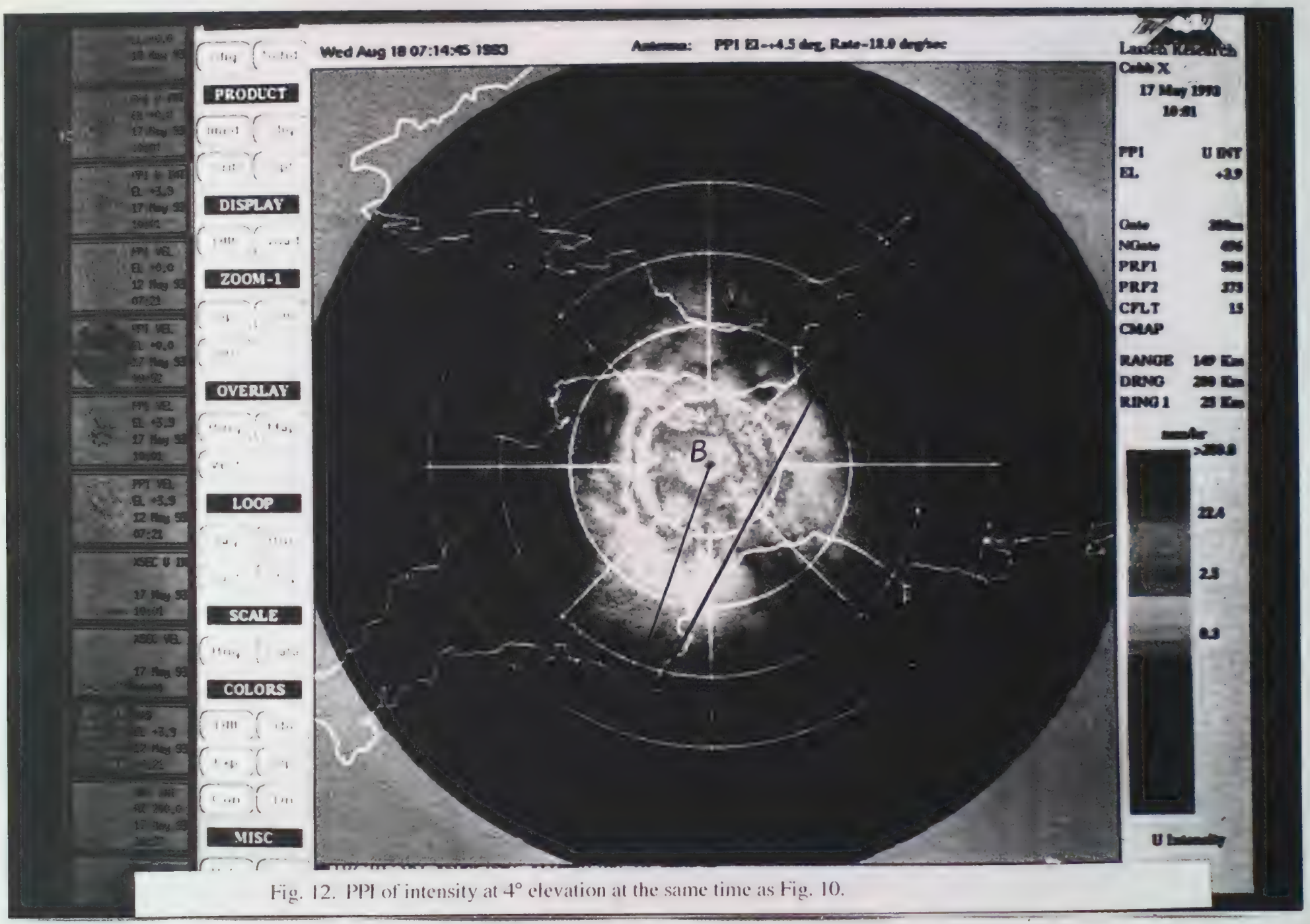

Fig. 12. PPI of intensity at 4° elevation at the same time as Fig. 10.

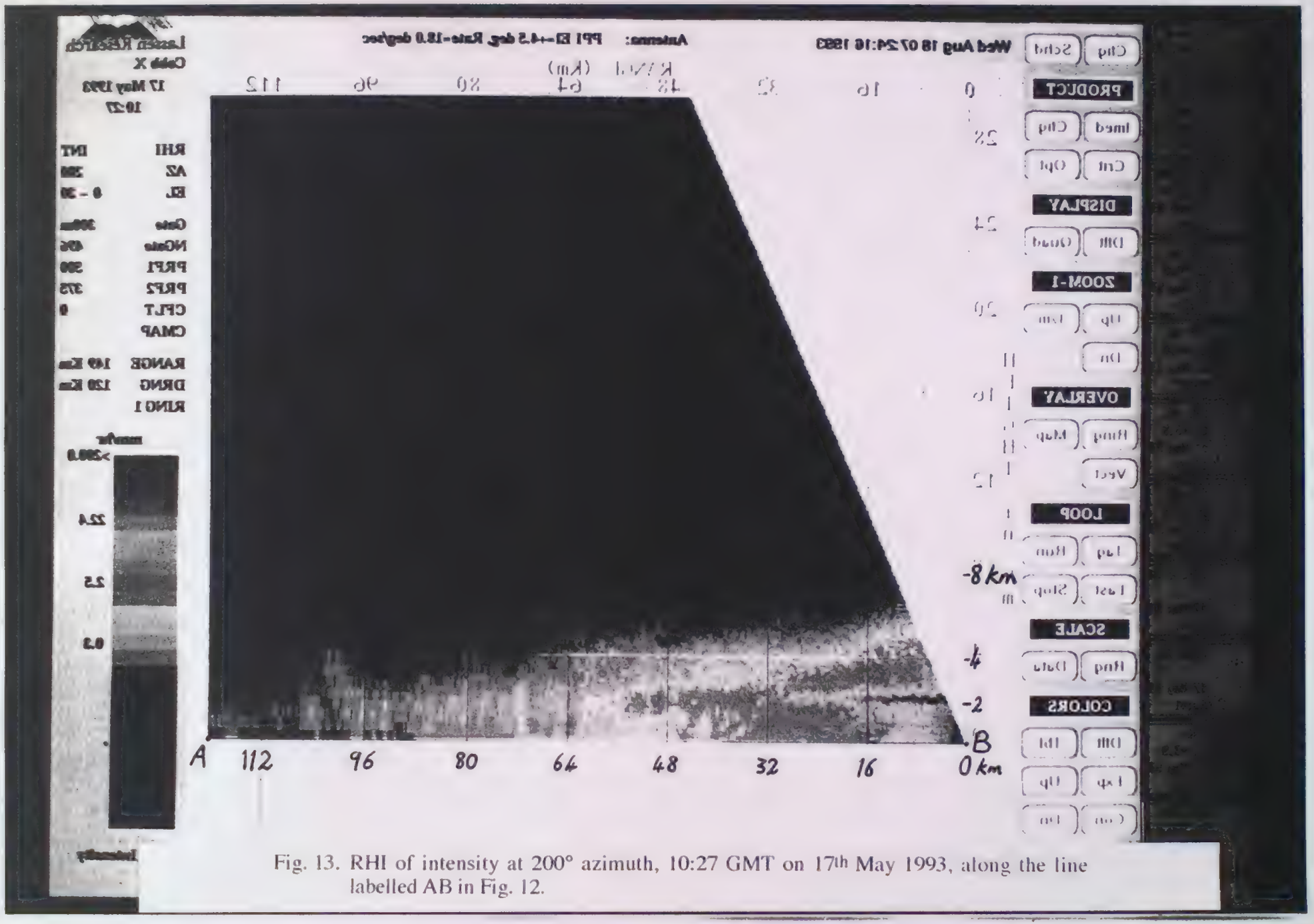

Fig. 13. RHI of intensity at 200° azimuth, 10:27 GMT on 17th May 1993, along the line labelled AB in Fig. 12.

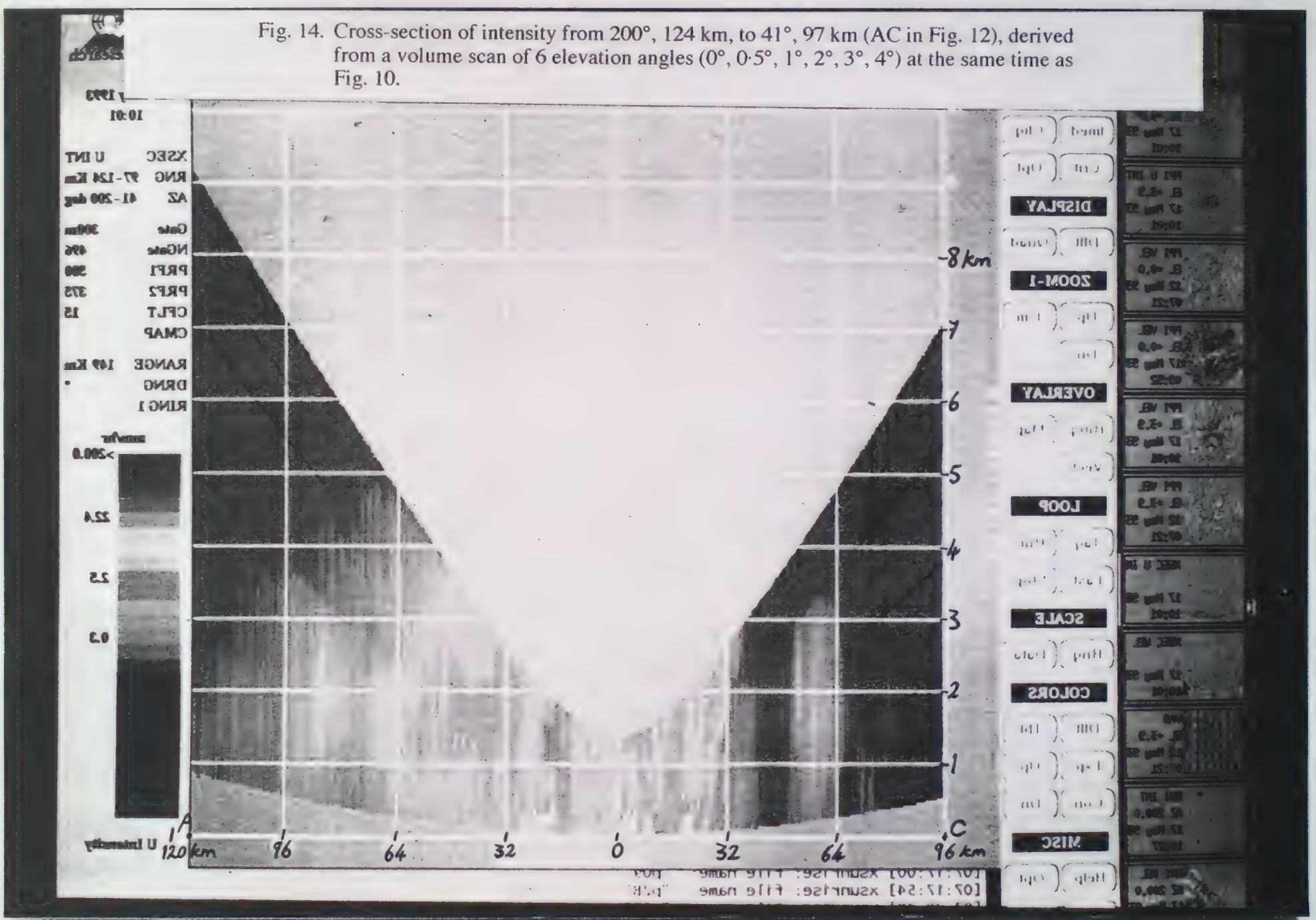

Fig. 14. Cross-section of intensity from 200°, 124 km, to 41°, 97 km (AC in Fig. 12), derived from a volume scan of 6 elevation angles (0°, 0·5°, 1°, 2°, 3°, 4°) at the same time as Fig. 10.

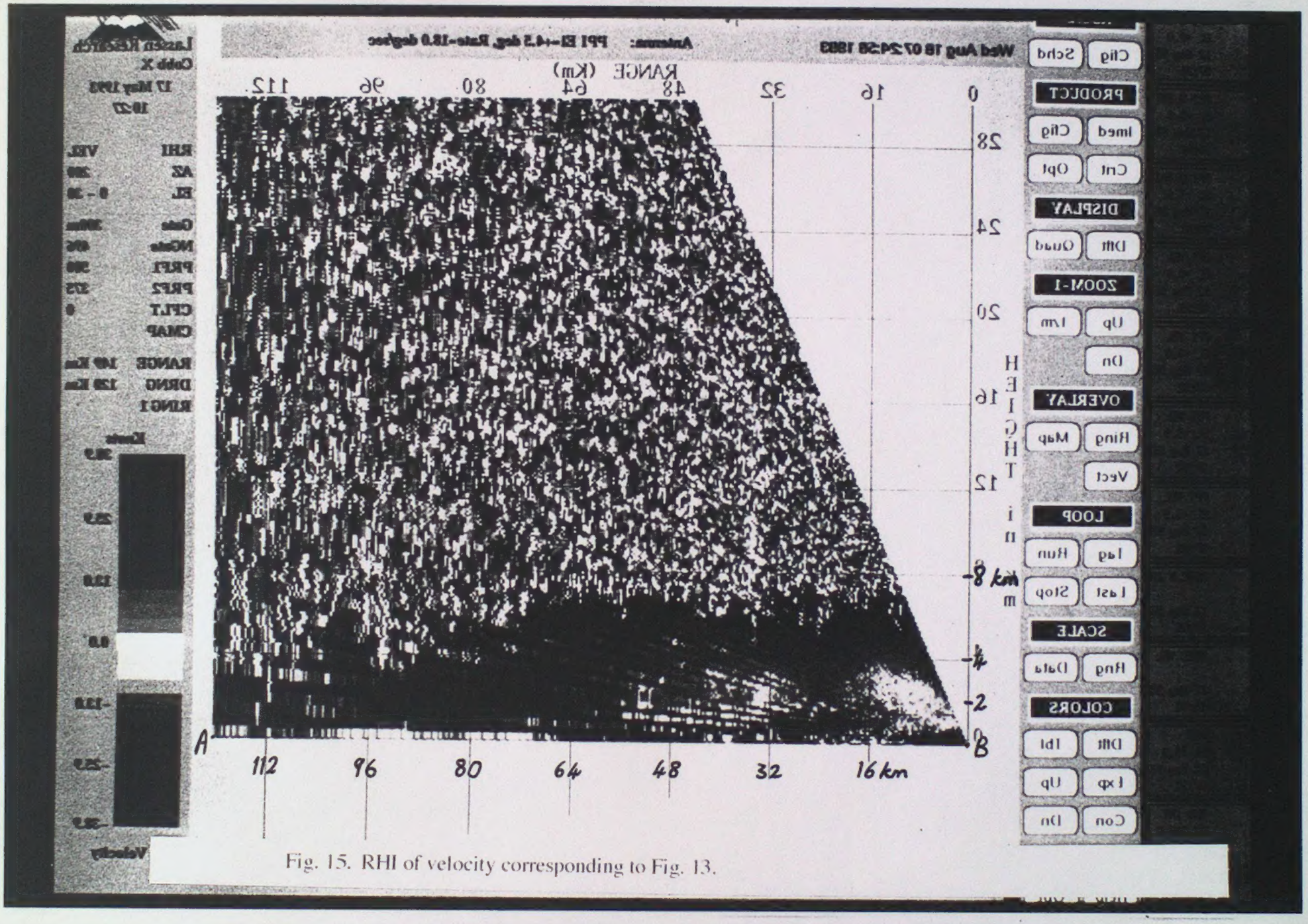

Fig. 15. RHI of velocity corresponding to Fig. 13.

Fig. 16. Cross-section of velocity corresponding to Fig. 14.

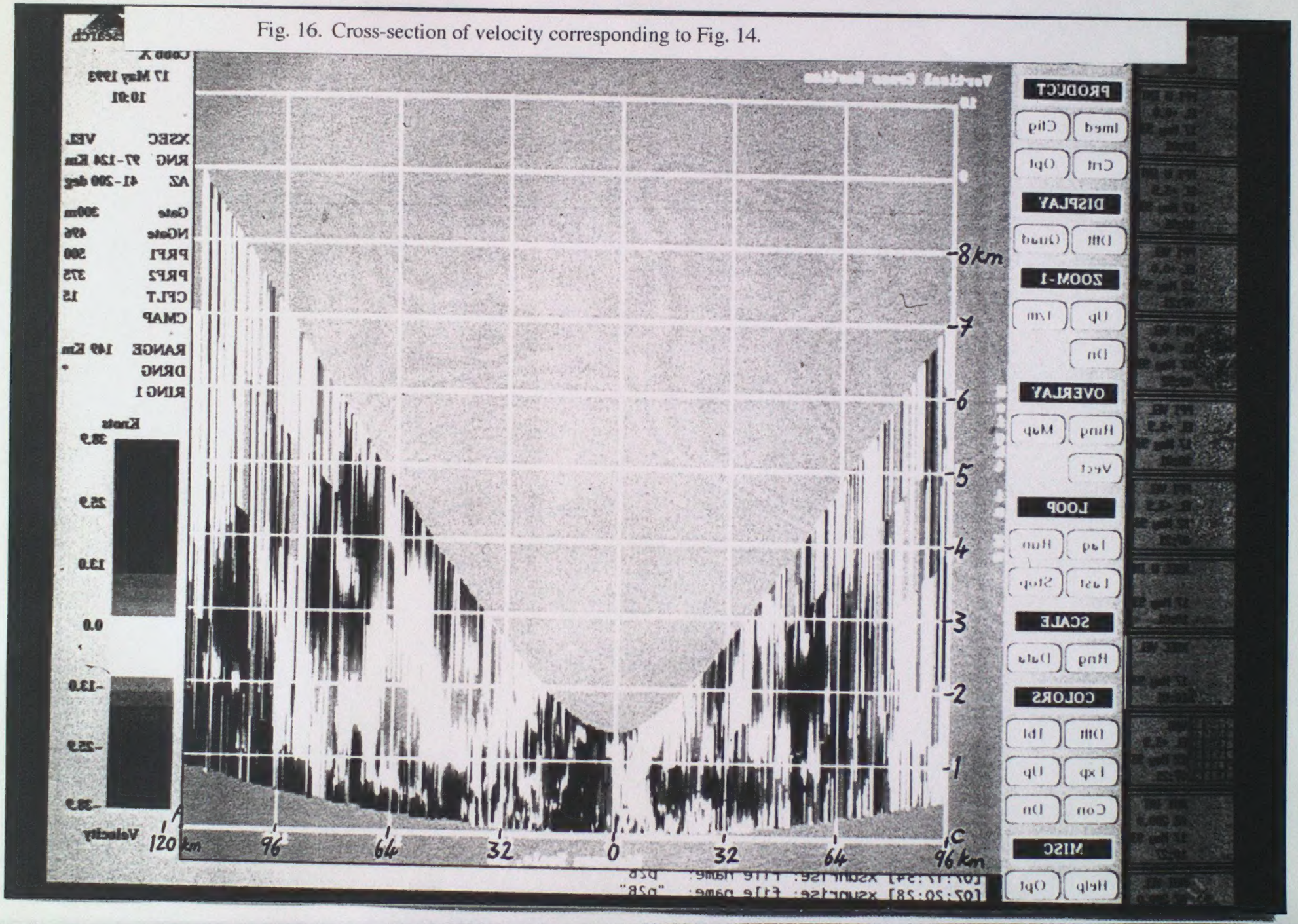

Fig. 17. Radiosonde ascent from Larkhill at 06:00 GMT on 12th May 1993 (compare Fig. 8).

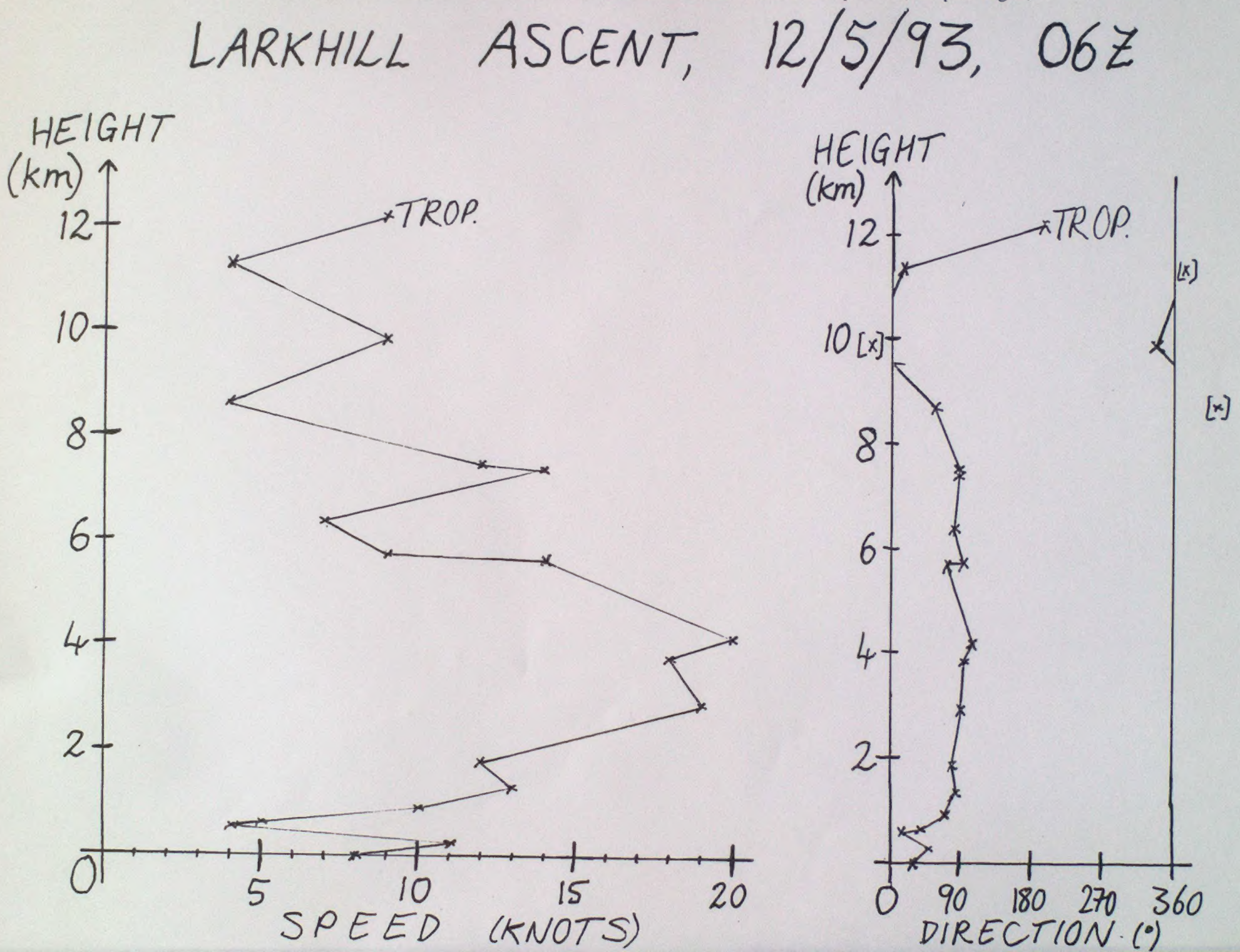
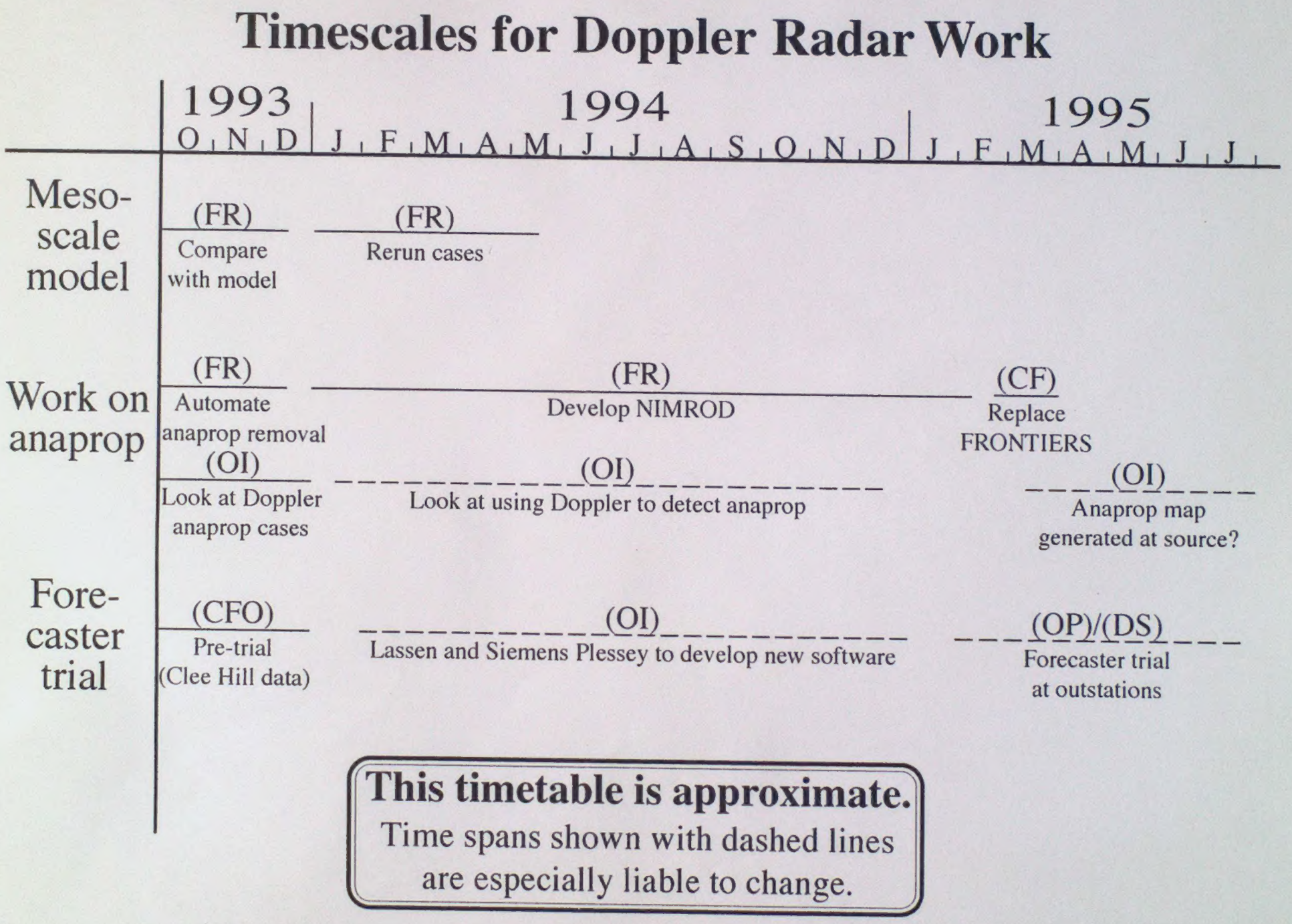
Fig. 18. Approximate timescales for work planned within the Met. Office on Doppler radar.